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ELECTRICAL FEEDTHROUGH DEVICE FOR USE IN A BALLISTIC ENVIRONMENT

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MAY 1988

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

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An electrical feedthrough device for use at pressures up to 700 MPa in a ballistic environment has been designed, built, and tested. This unit was designed around existing seal technology and can be installed in cavities machined to accept the Kistler 607C and the PCB 118 pressure transducers.

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I. INTRODUCTION

Interior ballistic studies at the BRL encompass a wide range of experiments dealing with the ignition, flamespread, and combustion of propellants. These studies may deal with an examination of process phenomena as in optical, flash x-ray, or interrupted burner studies, the derivation of high pressure propellant burning rates, as in closed bomb studies, or the chemistry of the processes involved in the combustion sequence of propellants. One common concern of each type of study is the reliable delivery of the energy necessary to initiate the process. Generally, whether the sequence is initiated by a hot wire, electric primer, or electric match, an electric feedthrough device is required to conduct the required current/voltage into the experimental fixture. The electric feedthrough can pose nettlesome problems, especially in experiments where gas temperatures can reach 3000 K and pressures approach 700 MPA.

There are many methods for constructing electrical feedthroughs for high pressure vessels. These include multiple variations of the traditional unsupported area design of Bridgman[1] from the 1930's using pipestone cones to act as both sealing agent and as electrical insulator. A not so reliable method is to seal small diameter wires into holes with the use of epoxies, highly compacted ceramic powders, or oils frozen with liquid gases. A good review of the above methods has been done by Downs and Payne.[2] A fairly recent approach that has seen good success has been the use of spherical sealing seats in conjunction with ball bearings and thin pieces of plastic.[3-4] As many high pressure experimenters can verify, the actual execution of a successful electrical feedthrough design for a given application frequently involves a number of trials and failures which, especially in the case of high pressure combustion experiments, can lead to significant equipment damage and repair costs.

A wide range of igniter electrode configurations have been explored in the BRL high pressure propellant characterization effort. In fact, the diversity of electrical feedthrough devices in the fixtures has resulted in a myriad of small parts and seals which has become clearly undesirable. To eliminate the potpourri of seal parts the decision was made to design a general purpose electrical feedthrough device for use up to 700 MPa (101,500 psi) in the closed bomb propellant combustion vessels. To simplify use in general range operations, this device has been designed specifically to be installed in the mounting cavity for Kistler 607 or PCB 118 piezoelectric pressure transducers, both of which are in common use at BRL. A picture of the resultant electrical feedthrough is shown in Figure 1.

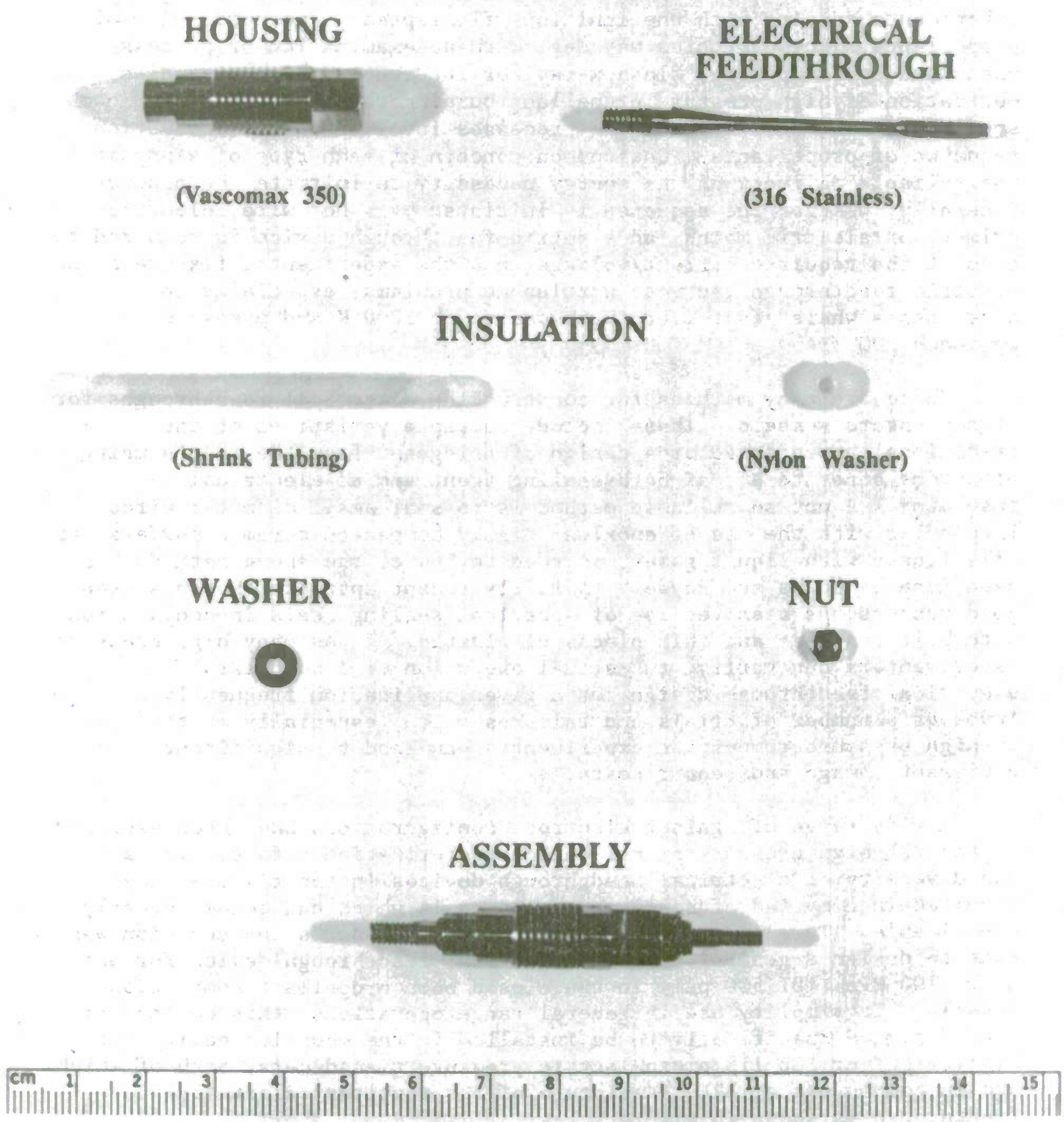

Figure 1. Photograph Showing the Electrical Feedthrough Both Assembled and Unassembled

II. DESIGN OF THE ELECTRICAL FEEDTHROUGH

The design requirements for the ignition device were as follows:

1. The mechanical aspects of the device are to be designed for pressures of 1000 MPa (145,000 psi).

2. The device must be reusable at 690 MPA.

3. The device must withstand the temperature extremes of up to 3000 K.

4. The device must fit into a Kistler 607C and a PCB 118 pressure transducer hole.

5. The device must be simple enough to be quickly rebuilt by virtually anyone with a minimum of instruction.

The actual design of the igniter was straightforward. The outer body dimensions and pressure sealing technique were determined by design requirement number four, compatibility with two commonly used pressure transducers. See Figures 2, 3, and 4 for drawings of the principle components of the electrical feedthrough. The outer body of the device (Figure 2) is machined out of a precipitation hardened steel, Vascomax 350, and heat treated to a 0.2% yield stress of 2300 MPa. While this is a fairly high yield stress for this material, the decision was made that the fixture body housing this device should fail before the feedthrough. The additional driving force for using this high value of yield stress is to insure that the fixture fails electrically before it fails mechanically. The center electrode (Figure 3) is machined from type 316 stainless steel. This is a work hardening stainless with excellent corrosion resistance. An electrode tip extension (Figure 4) is screwed on the end of the center electrode to prevent the combustion event from continually eroding the center electrode. This allows the user to inexpensively replace the one item that is in intimate contact with the harsh combustion environment.

The weakest area is the threaded section of the igniter body which must contain all of the force that is transmitted to the front face. An analysis of the threads follow.[5]

For the device in question, the pressure acts over a maximum diameter of 6.4 mm. At a pressure as high as 1000 MPa, the total axial force is 32,000 N. The total force that can be restrained may be calculated as follows:

The material that the electrode screws into has a 0.2% Yield Stress of 1100 MPa (160,000 psi). The shear stress is limited to 25% of the yield stress or 275 MPa. The effective diameter of the threads (3/8-24-UNF) is 8.6 mm, with an engaged thread length of 8 mm. The equivalent area resisting shear, including a 60% factor to allow for various stress raising effects, will be:

$$3.1416 \times 8.6 \times 8 \times .60 = 130 \text{ mm}^2$$

The total force able to be contained is:

$$275 \text{ MPa} \times 130\text{E-}6 \text{ m}^2 = 36{,}000 \text{ N}$$

This is above the maximum axial load force, at 1000 MPa (145,000 psi), of 32,000 N so the threads should not fail.

The average contact pressure on the area normal to the axis of the flanks of the threads should also be examined for possible thread seizure. With a mean diameter of 8.6 mm, the thread depth will be about 0.75 mm and the projected area will be 20 mm^2. Allowing a factor of 75% for mating imperfections and truncating, the net area is 15 mm^2. Since the engaged length is 8/1.06 pitches (thread length/thread pitch), the total flank area will be 15 x 8/1.06 or 113 mm^2. This gives a mean bearing pressure of about 283 MPa. While this bearing pressure seems a little high, this is taking into account the 50% over-design pressure. If the engaged threads are properly cut and lubricated with a small amount of molybdenum disulfide there should not be any problem with seizure.

If the threads are not going to fail, then the only other failure consideration is extrusion of the center electrode. An analysis of that possibility, by calculating the force necessary to cold extrude the center electrode,[6] quickly yields the fact that extrusion will not occur until pressures well past 1000 MPa.

Insulating the center electrode from the outer housing is easily accomplished using thin-walled heat-shrink tubing. Other materials may also be used depending on what is available or desirable. This includes: teflon tape, electrical tape, scotch tape, or even paper. For applications involving a vacuum, the use of an epoxy is recommended.

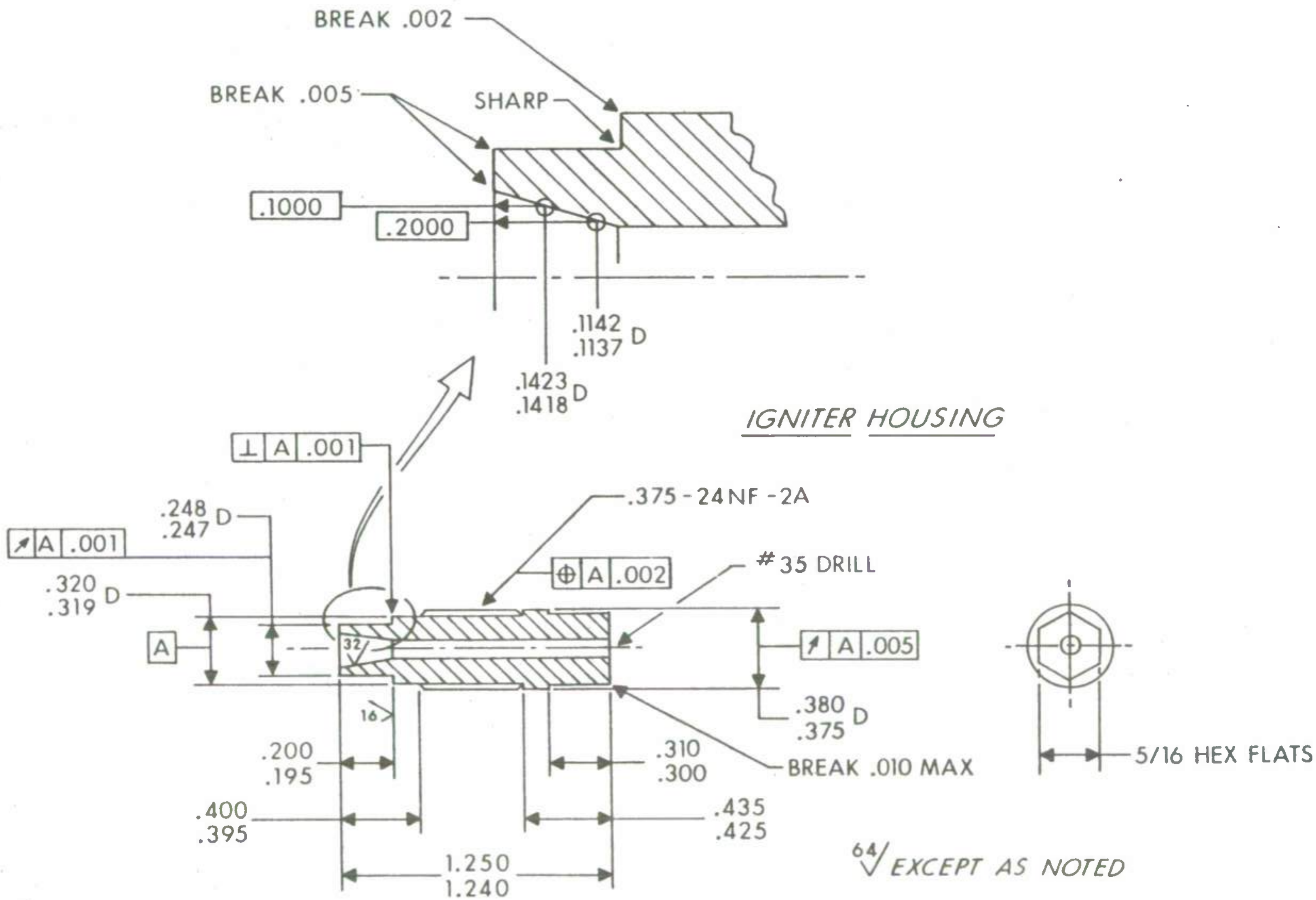

Figure 2. Igniter Body

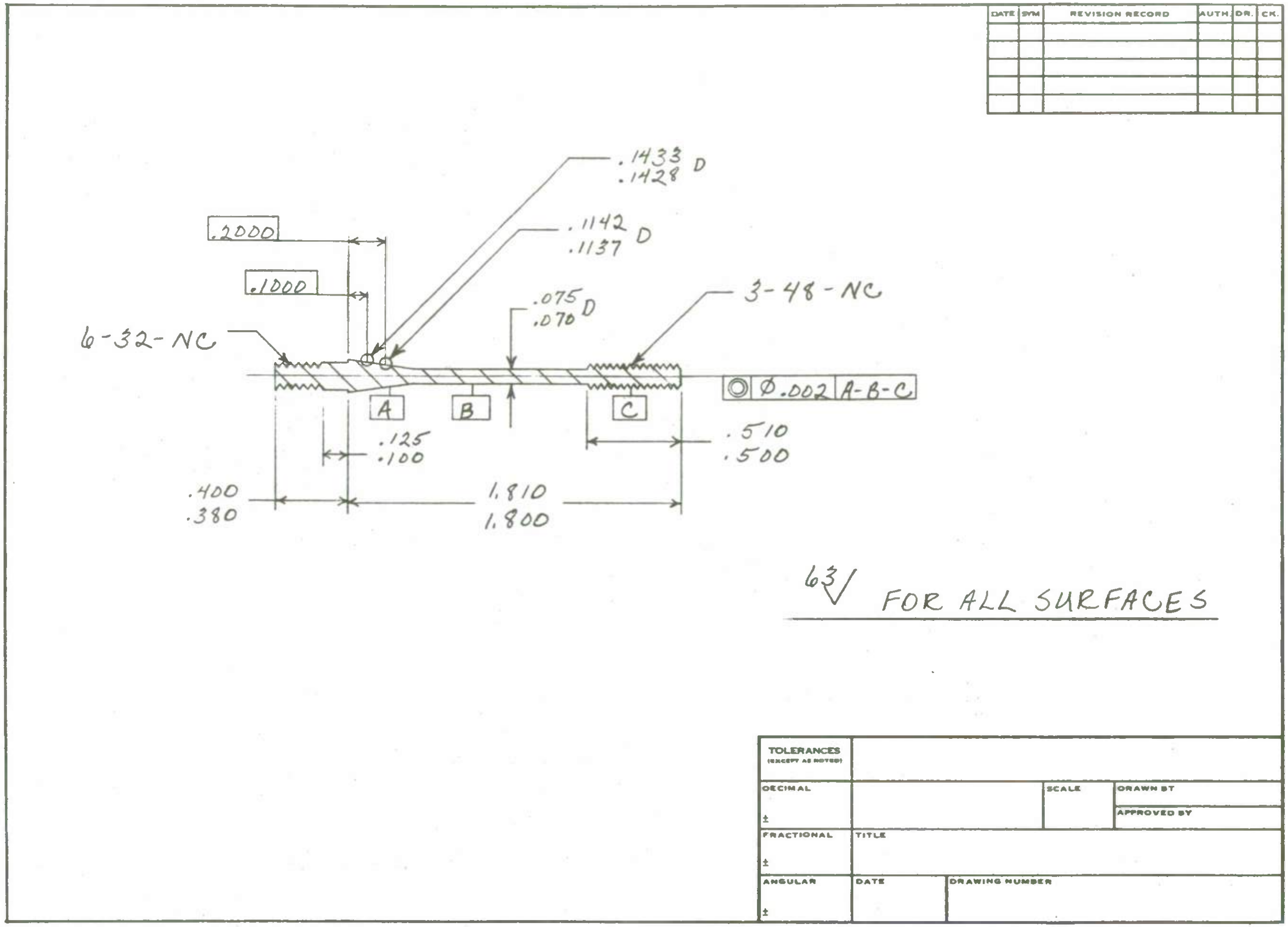

Figure 3. Igniter Center Electrode

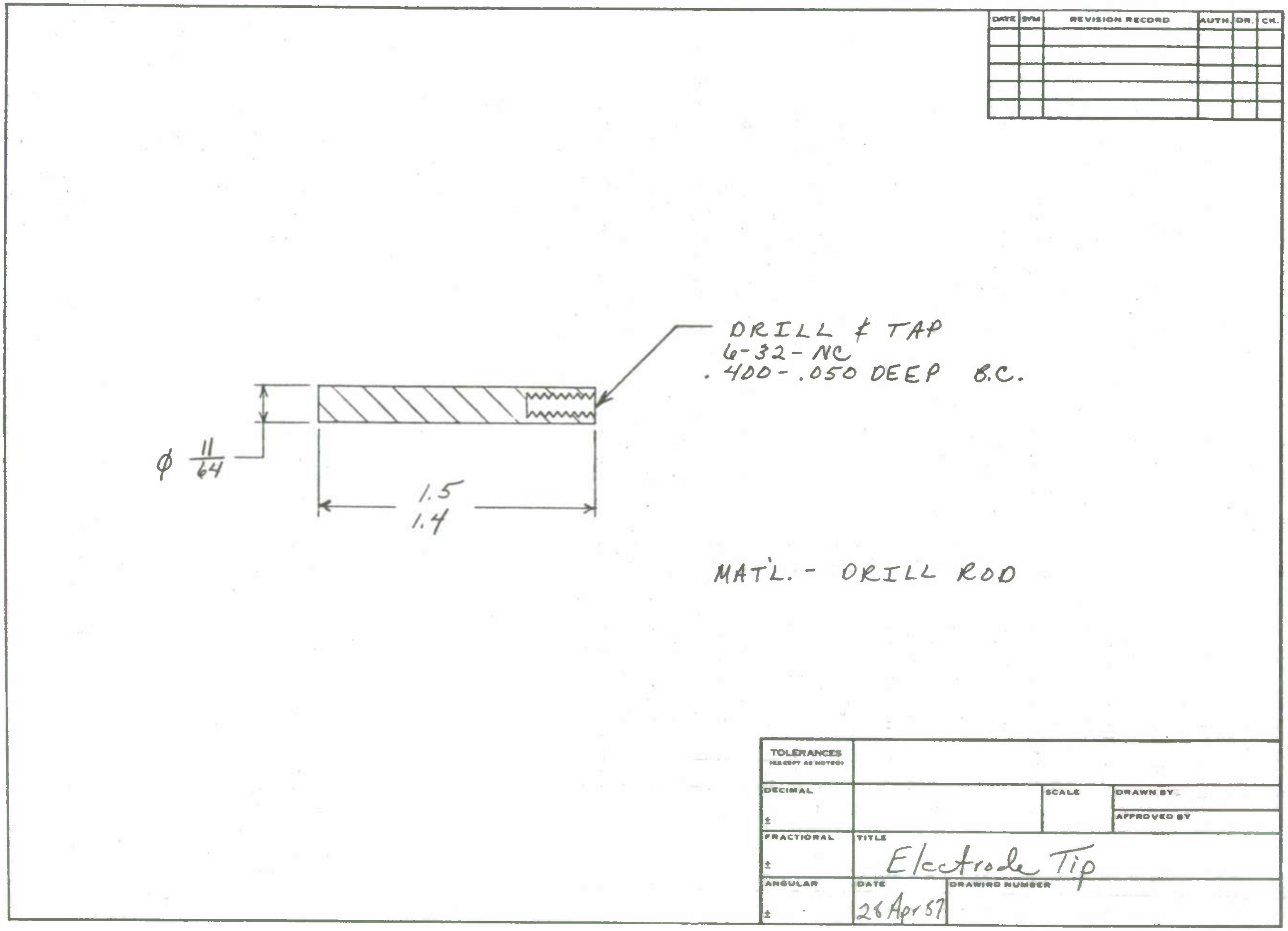

Figure 4. Center Electrode Extension

III. ASSEMBLY AND INSTALLATION

While assembly of the device is fairly simple, it is not foolproof and care must be taken to insure reliable operation. The insulation must be installed carefully to avoid shorting out the electrical signal. Before applying the insulator, insure that the electrode, the outer body, and the insulation are all clean and free of grit. Apply the insulation to the electrode in such a manner as to end with a uniform thickness of insulation, especially on the tapered portion of the electrode. Now insert the insulated electrode into the body, install the insulating washer, the steel washer, and snug the nut onto the screw threads. At this point it is recommended that the electrode be seated in the outer housing. This may be accomplished by rapping the interior end of the electrode on a hard surface or preferably by squeezing the assembly in a vise by using a 5/16 socket to protect the exterior threads of the electrode.

The device should be checked for continuity between the outer housing and the inner electrode after assembly. Once the user is satisfied that the insulation is integral, the device may be installed in a suitable cavity. Special care should be taken to make sure that there are no foreign particles in the cavity or on the feedthrough. The mounting threads should receive a scant coating of molybdenum disulfide lubricant prior to installation. The feedthrough should be tightened to 15-18 foot-pounds of torque to obtain a leakproof seal. A drawing of the mounting cavity is shown in Figure 5. There are special tools available from Kistler that will facilitate the machining of the mounting cavity. A list of these special tools and the sealing washers which may be purchased from Kistler may be found in Appendix A.

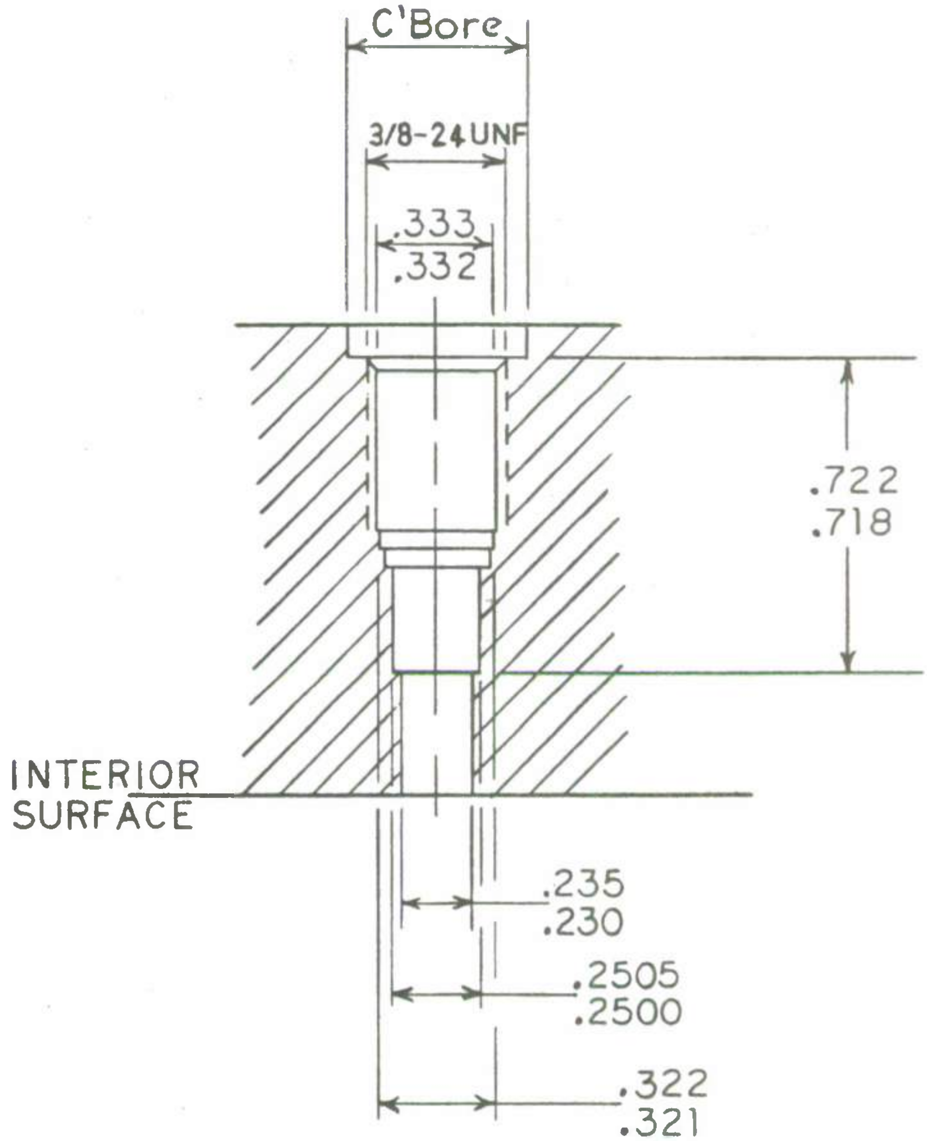

Figure 5. Igniter Mounting Cavity

IV. CONCLUSIONS AND FUTURE PLANS

An electrical feedthrough device has been designed, built and tested at 700 MPa in an environment of burning propellant. There are two parts to be machined and heat treated by trained personnel. Assembly and installation takes a minimum of time, especially for one familiar with installing piezoelectric transducers. This design has been routinely used at pressures of 690 MPa during closed bomb tests at the Ballistic Research Lab for over a year. It is expected that usage will extend to other experimental fixtures as well.

This type of electrical feedthrough device can easily be adapted to other pressure gauge configurations. There are also plans to build some optical or laser diagnostic ports using sapphire to replace the center electrode. In addition, there have been discussions about modifying the basic configuration to do heat flux measurements and bore surface temperature measurements.

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APPENDIX A

AVAILABLE SEALS AND TOOLING FOR MOUNTING THE ELECTRICAL FEEDTHROUGH

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This Appendix is included to list seals and tools that are available from the Kistler Instrument Corporation. The use and application of all of the items listed are described in the instruction manual for the 207C and the 607C high pressure transducers which is also available from the company.

Table 1A

Kistler Part Number	Description of Part
6000E42	Copper Seal
600A10	Stainless Steel Seal
600R1	Flat End Chucking Reamer
600R6	Flat End Chucking Reamer
600R8	Piloted Step-diameter Reamer

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